THE INHERITANCE OF RESISTANCE TO LEAF RUST AND BUNT, AND OF OTHER CHARACTERS IN THE WHEAT CROSS, TENMARQ X MINTURKI

by

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INTRODUCTION

The cross Tenmarq x Minturki was made for the purpose of developing an improved variety of wheat for Kansas. The present study was conducted in order to obtain fundamental information on the mode of inheritance of leaf rust and bunt resistance and other characters in this cross. An attempt was made to combine the winter hardiness and bunt resistance of Minturki with the high quality, early maturity, relative leaf rust resistance and stiff straw of Tenmarq. Although the desirable combinations were not obtained from this cross considerable information as to bunt resistance, leaf rust resistance and other plant characters was obtained.

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REVIEW OF LITERATURE

Leaf Rust Resistance

According to Johnston (25) heavy infections of leaf rust greatly reduce the yield of wheat. The loss in yield is attributed principally to a reduction in the number of kernels produced with a slight reduction in kernel size. Mains (28) states that reduced yields caused by leaf rust are due to the production of fewer and lighter kernels. Severe infections over long periods greatly reduced the number of kernels produced with a slight reduction in kernel weight. Infections over short periods resulted largely in decreased kernel weight.

Johnston and Melchers (26) found that certain varieties of wheat highly susceptible to certain physiologic forms of leaf rust in the seedling stage are very resistant to the same physiologic forms in the heading stage. This changing reaction to leaf rust was especially noticeable in certain hybrid plants, heterozygous with respect to leaf rust reaction. Many of the important types of common bread wheat

show this changing reaction to leaf rust. Plants resistant to leaf rust in the seedling stage are resistant in later stages of growth.

Mains and Jackson (29) report twelve physiologic forms of leaf rust of wheat. These different physiologic forms are distinguished by their reactions on different strains of wheat. With the exception of Vernal emmer no variety was found to be entirely resistant, in the seedling stage, to all of the physiologic forms of leaf rust. No form was found to which all of the varieties were susceptible. These writers state that agronomic varieties of wheat may not be uniform in their reaction to leaf rust.

Johnston (24) showed that strains of wheat which are resistant to a single physiologic form of leaf rust can be obtained by selection within a variety.

Mains, Leighty and Johnston (30) found leaf rust to be inherited in a very definite manner. They were able to determine under field conditions that resistance is heritable. Environmental factors prevented an accurate determination of ratios in some cases. In greenhouse experiments on seedlings from various crosses, resistance was found to be due to different factors or groups of factors, independently inherited. Resistance in some cases was dominant while in other cases susceptibility was dominant. Several of the crosses segregated in simple 3:1 ratios.

Mains (27) found evidence of resistance being due to different sets of factors in different lines of wheat.

Bunt Resistance

Tisdale and others (44) report that nearly all American wheats are more or less susceptible to bunt. The hard red winter wheats as a class are considered to be more resistant to bunt than the hard red spring, soft red winter or white wheat classes.

Gaines (18) concludes that bunt resistance of wheat is definitely heritable according to the commonly recognized laws of genetics. Types of hybrids possessing the accumulative resistance of both parents were observed. Bunt resistance is not considered to be linked (17) closely enough with any morphological characteristic to prevent the selection of a strain of any morphological type desired. Different varieties of wheat are thought to possess different types of resistance involving multiple factors.

Gaines and Singleton (19) state that resistance to bunt in the cross Marquis x Turkey is apparently caused by two factors, the one carried by Turkey being much more "prepotent" than the one carried by Marquis. Smith (40) in a cross between a hard red winter wheat resistant to bunt and a hard red spring wheat susceptible to bunt was able to

combine the bunt resistance of the winter wheat with the spring growth habit of the spring wheat. Types more resistant than the resistant parent were obtained.

Briggs (4) concluded that modifying factors influenced the resistance of certain varieties of wheat to certain physiologic forms of bunt. Part of the variability observed in heterozygous and homozygous susceptible F_3 hybrids was thought to be due to modifying factors.

Aamodt (1) believes bunt resistance is governed by multiple factors. In eight of the nine crosses which he studied the average percentage of bunt infection of the hybrids was intermediate between that of the two parents. In one cross the average percentage of bunt infection was greater than that of either parent.

Briggs (5) using a single physiologic form of bunt found Hussar wheat to differ from White Federation and Hard Federation by two main genetic factors. The presence of other factors may become apparent if other physiologic forms of bunt are used. Odessa crossed with White Federation (6) and Banner Berkeley crossed with the same variety (7) showed only one main factor difference. Banner Berkeley, Martin and White Federation are thought to have identical factors for bunt resistance. Turkey crossed with White Federation (8) gave a single main factor difference for resistance to

bunt. This factor resembles the second Hussar factor in that about half of the heterozygous plants become infected with bunt.

Dillon-Weston (15) noticed that bunted wheat plants were heavily infected with yellow rust and that bunt-free plants were comparatively free from yellow rust. Rust resistance was thought to be broken down in plants contaminated with bunt.

Winter Hardiness

Clark, Martin and Parker (12) studied the comparative hardiness of winter wheat varieties in uniform winter-hardiness nurseries in the Great Plains.

Quisenberry and Clark (36) state that low temperatures cause nearly as heavy losses to the wheat crop as all wheat diseases combined.

Quisenberry (34) and Quisenberry and Clark (35) conclude that winter hardiness is controlled by several genetic factors. Environmental conditions are thought to greatly influence the expression of winter hardiness. Difficulty in combining winter hardiness and earliness was experienced. Ball (2) states that, "cold injury to wheat may be due to one or more of many different factors in the environment." Hayes and Aamodt (21) consider the inheritance of winter

hardiness to be very complex and without doubt due to several genetic factors.

Martin (31) found the F_3 hybrids in the crosses which he studied to be mostly intermediate between the two parents in winter hardiness. Hayes and Garber (22) report that in a cross between Odessa and Turkey a few selections were obtained which were as hardy or hardier than Odessa, the hardy parent. One of these hardy selections was named Minturki and is now grown in southern Minnesota.

Clark, Martin and Parker (12) report Minturki to be considerably more winter hardy than varieties such as Kanred and Kharkov. Hill and Salmon (23) found Minturki to be relatively hardy when subjected to artificially produced low temperatures if thoroughly hardened off before freezing.

Earliness and Plant Height

Thompson (42) concludes that earliness can be combined with other desirable characteristics by Mendelian methods but that it is necessary to use large numbers of individuals. Several genetic factors (43) are thought to be involved in the inheritance of earliness. Freeman (16) considers time of heading to be governed by three or more "Mendelizing" unit factors.

Clark (9) observed a negative correlation between date

of heading and yield. Early maturing plants were more productive than late maturing plants. The amount of correlation between date of heading and plant height in hybrids of Kota x Hard Federation increased with increasingly unfavorable environmental conditions. Early plants had a tendency to be short, and late plants had a tendency to be tall.

Quality Factors

Roberts (37) concludes that protein content in wheat is an inheritable character. Some varieties are considered to be more flexible than others in regard to protein content, when grown under varying climatic conditions. Clark, Florell and Hooker (10) report kernel texture to be strongly inherited in F_3 hybrids. Several genetic factors appeared to be involved. Biffen and Engledow (3) consider gluten strength to be an inheritable character. In several of the crosses which they studied the hybrids tended to segregate into "weak," intermediate and "strong" gluten strength groups in the proportions of 25, 50 and 25 per cent, respectively.

Swanson and Kroeker (41) are of the opinion that two characteristics pertaining to baking quality are inherited, namely; resistance to mechanical action and response to oxidizing agents. These characteristics appear to be

antagonistic and the varieties which possess the one appear to lack the other.

Hayes (20) in crosses between Marquis and Preston and Marquis and Haynes Bluestem concludes that kernel plumpness is strongly inherited and is associated with high plant yield. Inheritance of kernel size is thought to be due to multiple factors.

Within a given sample of wheat Newton, Cook and Malloch (32) found vitreous kernels to be harder and to contain more protein than starchy kernels. Shollenberger and Clark (39) state that wide variations in the milling and baking qualities occur within a variety of wheat due to the season and locality in which the crop is grown. Minturki when grown under dry conditions produces softer grain than Turkey, Kharkov or Kanred but under the more humid conditions of Minnesota the kernels of Minturki are as hard as the kernels of other hard red winter wheat varieties. Tenmarq (41) was found to be fully equal to any of the older and more extensively tested hard red winter wheats in baking quality.

Pelshenke (35) of the University of Halle, Germany, assigned numerical standards for gluten quality, measured by the time consumed from the beginning of fermentation to the first bursting of the dough ball. Specific gluten quality was obtained by dividing the time in minutes required

for the dough ball to burst by the percentage of protein in the wheat. Saunders and Humphries (38) used a method similar to the one used by Pelshenke in determining the baking value of flour samples. Cutler and Worzella (14) found a high "time" test for bread flour and a low "time" test for pastry flour. They used this method in determining the quality of new hybrids.

MATERIALS AND METHODS

Tenmarq and Minturki were used as parents in this cross because of the strongly contrasted characters which they possess. A combination of the desirable characteristics of these two varieties would result in a superior variety of wheat for growing in Kansas. The contrasted characters of these varieties are as follows:

Characters	Tenmarq	Minturki
Winter hardiness	Semihardy	Very hardy
Heading period	Medium early	Midseason to late
Leaf rust reaction	Relatively resistant	Susceptible
Bunt reaction	Highly susceptible	Resistant
Quality of grain	Hard	Semihard
Shape of kernel	Short	Midlong
Strength of straw	Stiff	Weak

Tenmarq is described by Clark, Parker and Waldron (13) as follows:

"Tenmarq (Kan. No. 349, C.I. No. 6936) was produced from a hybrid between Marquis and P-1066. The latter is a selection similar to Kanred, both from Crimean, C.I. No. 1435. The cross was made in 1917 from the crop of

1916-'17 at Manhattan, Kan., and Tenmarq is the result of a selection made in 1921. It was developed by the agronomy department of the Kansas Agricultural Experiment Station in cooperative experiments with the Office of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

"Tenmarq is bearded and has white glabrous glumes, long beaks, and short hard red kernels. It is a true winter wheat, but the grain is sometimes graded as hard red spring or mixed. Its superior characters are high yield, excellent quality, early maturity, and stiff straw. Its chief defects are that it is susceptible to Hessian fly attack and has only slightly greater winter hardiness than Blackhull."

Minturki was produced from a cross between Odessa and Turkey made in 1902 at the Minnesota Agricultural Experiment Station. It is grown in Minnesota and by experiment stations in other northern and western states. Clark, Martin and Ball (11) describe Minturki as follows:

"Plant winter habit, midseason, midtall; stem white, weak; spike awned, fusiform, mid-dense, inclined; glumes glabrous, yellowish white, midlong, narrow; shoulders wanting to narrow, oblique; beaks 1 to 3 mm. long; awns 4 to 8 cm. long; kernels red, midlong, semihard, ovate to elliptical, acute; germ small; crease narrow, shallow to mid-deep; cheeks rounded; brush small, midlong to long.

"This variety is very winter hardy. It resembles Turkey except in having softer kernels and in being more winter hardy."

Typical kernels of Tenmarq and Minturki are shown in Plate I. Under Kansas conditions Minturki produces a semihard grain as compared to the very hard grain produced by Tenmarq. As shown in Table 1, Tenmarq, under Kansas conditions, is earlier than Minturki. For the eight-year period,

Plate I.-- Typical kernels of Tenmarq (above) and Minturki (below).

Table I.—Agronomic data on Tenmarq and Minturki grown in winter hardiness nursery at Manhattan, 1925 to 1932, inclusive.

Year and Variety	Winter survival (Per cent)	Date first headed May	Date ripe June	Plant height (Ins.)	Lodging (Per cent)	Leaf rust (Per cent)	Acre yield (Bus.)	Test weight per bushel (Lbs.)	Kernel plumpness (Per cent)	Yellow berry (Per cent)
Tenmarq										
1925	100.0	15	15	41.0	0.0	5-15	36.2	59.5	75	---
1926	93.0	20	16	35.0	.0	---	20.5	55.0	68	---
1927	95.5	19	28	--	.0	75	38.9	54.4	75	58
1928	68.6	20	21	36.0	.0	---	56.3	60.4	87	38
1929	96.4	25	26	45.0	5.0	20-40	30.8	56.5	85	tr.
1930	94.0	19	25	45.0	27.0	10	35.9	60.3	85	18
1931	100.0	25	23	42.0	63.0	25	49.8	59.8	78	27
1932	99.0	19	20	44.0	37.0	18	58.3	61.8	87	5
Av....	93.2	20	22	41.1	16.5	---	42.6	58.2	80	---
Minturki										
1925	100.0	19	20	40	10.0	60-70	25.2	58.5	72	---
1926	97.0	23	16	35	.0	---	20.2	50.3	58	---
1927	96.6	25	28	--	7.0	50	25.4	56.4	83	95
1928	93.8	21	26	37	.0	---	49.2	60.4	85	43
1929	92.0	28	7/2	48	.0	57-77	30.3	55.8	86	tr.
1930	92.0	23	28	48	27.0	70	42.1	60.4	83	dull
1931	97.0	29	26	46	36.0	56	41.9	58.8	83	75
1932	97.0	22	23	47	3.0	50	47.0	52.3	86	13
Av....	95.7	24	25	43	10.3	---	34.9	56.6	79	---

1925 to 1932, inclusive, Tenmarq averaged four days earlier in heading and three days earlier in ripening than Minturki. Minturki had an average height of 43 inches compared to an average height of 41 inches for Tenmarq. The data shown in Table I are from the winter-hardiness nurseries grown at Manhattan.

Tenmarq has an average test weight of 58.2 pounds for the eight-year period and Minturki has an average test weight of 56.6. Kernel plumpness notes average about the same for both varieties. Minturki has a slightly higher average per cent winter survival than Tenmarq. Differences in winter survival were very small with the exception of 1928 when Minturki had a winter survival of 93.8 per cent as compared to only 68.8 per cent survival for Tenmarq. As shown in Table I Tenmarq usually has a lower percentage of leaf rust infection than Minturki. It will be noticed, however, that the difference in percentages of infection varies greatly from year to year. In 1927 there was very little difference in the amount of leaf rust infection recorded on the two varieties, both appearing rather susceptible. In 1930 Minturki was rather susceptible while Tenmarq showed marked resistance.

The percentage of bunt recorded in the botany nursery at Manhattan on Tenmarq and Minturki shows Minturki to be

resistant and Tenmarq to be susceptible. Bunt infections recorded on these varieties during the four-year period, 1929 to 1932, are as follows:

Year	Per Cent Bunt Infection	
	Tenmarq	Minturki
1929	42.6	2.3
1930	23.5	4.6
1931	24.0	2.2
1932	65.8	17.4
Average	39.0	6.6

Data on bunt infection collected on Tenmarq and Minturki at other experiment stations are in agreement with results obtained at Manhattan. In 1929, based on data collected at nine experiment stations in the winter wheat area, Tenmarq averaged 21.5 per cent bunt infection and Minturki, 2.7 per cent infection. In 1932 in a similar test at eight stations Tenmarq averaged 37.6 per cent bunt and Minturki, 5.7 per cent. Normal and bunted kernels of wheat are shown in Plate II.

The cross Tenmarq x Minturki was made in the agronomy greenhouse at Manhattan, Kan., during the winter of 1926-'27. The F_1 generation consisting of six F_1 plants was grown in the greenhouse during the winter of 1927-'28. The seed from each F_1 plant was kept separate and space-planted in the agronomy nursery at Manhattan in the fall of 1928 to produce the F_2 population grown in 1929.

Plate II.-- Normal (upper) and bunted (lower) kernels of wheat.

F_3 lines selected from individual F_2 plants were grown in the agronomy nursery at Manhattan and at Colby, Kan., in 1930. Thirty-six lines were grown in space-planted rows at Manhattan and thirty-two lines were grown at Colby but were not space-planted. At Manhattan only F_3 plants noted as resistant to leaf rust in the heading stage in 1930 were selected for growing the F_4 lines in 1931. Individual head selections were made from the F_3 lines at Colby. These selections were made at random as far as resistance to leaf rust was concerned.

One hundred and forty-nine F_4 lines, selected from individual F_3 plants grown at Manhattan in 1930 and noted as resistant to leaf rust in the heading stage, were grown in uniform space-planted rows in the agronomy nursery at Manhattan, at Colby, Kan., and North Platte, Nebr., in 1931. One hundred of these same F_4 lines were also grown in space-planted rows at Akron, Colo. These uniform nurseries were grown primarily for obtaining information on the winter hardiness of the hybrid lines. Parental checks were planted in each of the nurseries. Ninety-six individual head selections from the F_3 lines grown at Colby in 1930 were grown in space-planted nursery rows at Manhattan in 1931.

Seed of 31 F_2 plants, selected from the F_2 population grown at Manhattan in 1929, was inoculated with a Kansas

composite of physiologic forms of bunt and planted in the botany nursery at Manhattan in the fall of 1930 for growing the F_3 lines in 1931. Many of these same F_3 lines were also grown in the agronomy nursery. The F_4 lines grown at Manhattan, Colby and North Platte were also grown in the botany nursery, and were inoculated with the same bunt inoculum as the F_3 lines. Both the F_3 and F_4 lines were grown in space-planted rows one rod long. The percentage of bunted plants occurring in each F_3 and F_4 line was determined.

The F_5 lines grown in 1932 were selected from individual plants of F_4 lines that were bunt-free in 1931. The F_5 lines were inoculated with a Kansas composite of physiologic forms of bunt and grown in the botany nursery in 1932. Bunt notes taken in 1932 represent the percentage of bunted heads occurring in each line. It was impossible to determine the number of bunted plants since the material was not space-planted. F_6 lines selected from F_5 plants of bunt-free F_5 lines are being grown in the botany nursery in 1933. These hybrid lines were also inoculated with a Kansas composite of physiologic forms of bunt.

F_3 and F_4 seedling plants were inoculated with known physiologic forms of leaf rust in the two-leaf stage during the winter of 1930-'31. Different F_3 and F_4 lines were

grown in individual pots and the reaction of the seedlings of each individual line to various physiologic forms of leaf rust determined. F_3 seedling plants were inoculated with physiologic forms, 3 and 9. F_4 lines were inoculated with physiologic forms 9, 15 and 26. The F_4 lines used in these seedling inoculation experiments were selected from F_3 plants noted as resistant to leaf rust in the heading stage in the agronomy nursery in 1930. These are the same lines that were grown in the agronomy and botany nurseries at Manhattan and in the nurseries at Colby, North Platte, Nebr., and Akron, Colo., in 1931.

EXPERIMENTAL RESULTS

Resistance to Leaf Rust, *Puccinia triticina*

Reaction of Hybrids in the Heading Stage. The reaction of the hybrids to leaf rust was determined in the heading stage in the field and in the young plant stage in the greenhouse. The percentage of leaf rust in the heading stage in the field was determined on the F_2 population and on F_3 and F_4 lines grown in the agronomy nursery. Seedling inoculations with several known physiologic forms of leaf rust were made on plants of F_3 and F_4 lines in the greenhouse.

The estimated field infection of the six F_2 populations from six F_1 plants varied from 50 to 70 per cent to

80 to 90 per cent. This is the only information available on the rust reaction of the F_2 generation which was grown in the agronomy nursery in 1930. Notes on the rust reaction of the individual F_2 plants would have been much more reliable than the general row note. This F_2 population was evidently segregating for factors governing resistance to leaf rust, as shown by results obtained in F_3. Tenmarq had 10 to 70 per cent leaf rust compared to 70 to 80 per cent for Minturki.

Thirty-six F_3 lines from individual F_2 plants were grown in single space-planted eight-foot rows in the agronomy nursery in 1930. Each F_3 line was either resistant, segregating or susceptible to leaf rust. The different classes of infection were very easily distinguished. Six F_3 lines were homozygous susceptible, 16 were segregating for resistance and 14 were homozygous resistant. The rust reaction of the individual plants in the segregating rows was determined. As shown in Table II, 269 plants in the segregating rows were found to be susceptible and 83 resistant. A few of the plants in the segregating rows appeared to have an intermediate reaction. They were placed in the susceptible class. On the basis of a 3:1 ratio there is a deviation of 5 ± 5.48 from normal expectancy. This is considered to be a very close fit. The data indicate that resistance to leaf rust in this cross is

Table XI.-- Reaction to leaf rust of individual plants of F_3 lines of Tenmarq x Minturki, segregating for resistance to leaf rust, heading stage.

Agronomy nursery, 1930.

Row No.	Number of plants		
	Susceptible	Resistant	Total
5074	15	7	22
5076	19	4	23
5077	13	9	22
5082	21	5	26
5083	13	8	21
5086	17	9	26
5087	16	5	21
5088	14	6	20
5092	17	4	21
5097	15	2	17
5098	22	2	24
5099	15	7	22
5101	19	1	20
5102	16	6	22
5104	20	5	25
5107	17	3	20
Total Obs.	269	83	352

Calc. (3:1)	264	88	Dev. 5 ± 5.48
			$\frac{\text{Dev.}}{\text{PE}} = .912$

due to a single main genetic factor with susceptibility dominant. Kinturki was very susceptible to the prevalent physiologic forms of leaf rust in 1930 while Tenmarq showed marked resistance. Leaf rust infection on Tenmarq varied from a trace to 25 per cent. Tenmarq was more resistant to the physiologic forms of leaf rust prevalent in the agronomy nursery in 1930 than in most seasons. Leaves of resistant and susceptible hybrids and leaves of the two parents are shown in Plate III. Tenmarq usually shows some resistance to leaf rust but not so much as indicated in this photograph.

Resistant F_3 plants from resistant rows and resistant F_3 plants from segregating rows were tagged in the field in 1930. In selecting F_3 plants for growing F_4 lines in 1931, only those plants marked rust resistant were saved. Other characteristics such as general plant vigor, uniformity of tillers and heads; and shape, texture and plumpness of kernels were also considered in making these selections.

Thirty-two F_3 lines were grown at Colby in 1930. These were not space-planted, hence individual plant selections could not be made. Individual head selections were made from these F_3 lines disregarding the reaction of the plants to leaf rust.

One hundred and forty-nine F_4 lines selected from rust-resistant F_3 plants were grown in the agronomy nursery in

Plate III.-- Leaf rust infection of Tenmarq (resistant), Minturki (susceptible) and of susceptible and resistant F_3 plants of Tenmarq x Minturki.

(a) Susceptible F_2 hybrid

(b) Resistant F_2 hybrid

(c) Tenmarq

(d) Minturki

1931. Eighty-six F_4 lines selected from F_3 lines grown at Colby in 1930 were also grown in the agronomy nursery in 1931. The F_4 lines selected from F_3 lines grown at Colby in 1930 were selected more or less at random as far as leaf rust reaction is concerned and should be representative of an unselected population as far as this character is concerned. The F_4 lines selected from the resistant F_3 plants showed considerable leaf rust infection. There is considerable difference in the amount of infection in the two groups of selections, one from F_3 plants selected at Manhattan and known to be resistant, the other from F_3 plants selected at Colby without reference to leaf rust reaction. The F_4 lines unselected for rust resistance had an average leaf rust infection of 43 per cent. The F_4 lines selected from resistant F_3 plants had an average infection of only 24 per cent. Tenmarq had an average infection of 33 per cent and Minturki an average infection of 31 per cent. The F_4 lines selected from the rust-resistant F_3 plants are more resistant as a group than either parent. The percentages of leaf rust infection of the two groups of F_4 lines and the parents are shown in Table III. The data are presented graphically in Figure 1. There is evidence of transgressive segregation for resistance to leaf rust in this cross. A combination of factors for moderate resistance from the two parents has resulted in considerably more resistance in some

Table III.-- Leaf rust infection of F_4 lines from rust-resistant F_3 plants and from F_3 plants selected at random.

Agronomy nursery, 1931.

Leaf rust infection	F_4 lines from rust-resistant F_3 plants		F_4 lines from F_3 plants selected at random		Parental check rows			
					Tenmarq		Minturki	
Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
0-14	19	12.8	---	----	---	---	---	---
15-24	60	40.3	3	3.5	3	23.1	1	7.7
25-34	63	42.3	26	30.2	6	46.2	10	76.9
35-49	7	4.7	32	37.2	3	23.1	2	15.4
50-64	---	---	23	26.7	1	7.7	---	---
65-79	---	---	2	2.3	---	---	---	---
Total,	149	---	86	----	13	---	13	---
Av. ..	---	24.1	--	42.8	--	33.0	---	31.6

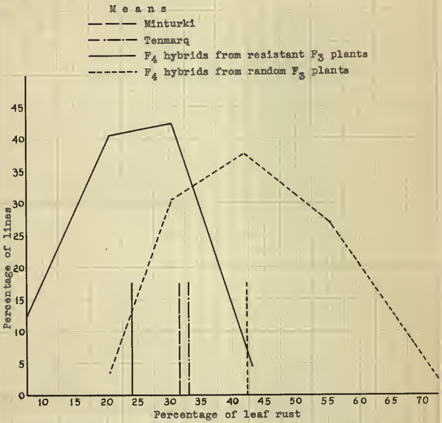


Fig. 1.-- Leaf rust infection of F_4 lines from rust-resistant F_3 plants and from F_3 plants selected at random, agronomy nursery, 1931.

of the hybrids than is shown by either parent.

The physiologic forms of leaf rust present in 1931 were apparently different from the forms prevalent in 1930, judging from the susceptible reaction of Tenmarq recorded in 1931. Tenmarq had an average infection slightly higher than Minturki in 1931.

Reaction of F_3 and F_4 Hybrids to Known Physiological Forms, in the Seedling Stage. Plants of F_3 and F_4 lines in the two-leaf seedling stage were inoculated with known physiologic forms of leaf rust in the greenhouse during the winter of 1930-'31. The F_3 seedlings were inoculated with physiologic forms 3 and 9 and the F_4 seedlings were inoculated with forms 9, 15 and 26. Plants of each hybrid line were grown in a separate pot for each inoculation made. Approximately 20 seedlings were grown in each pot. Parental checks were inoculated with each of the physiologic forms.

Twenty-five F_3 lines were inoculated with leaf rust physiologic form 3. Nearly all of the seedlings were susceptible to this form of rust. There were a few seedlings in seven of the pots that showed some resistance as evidenced by small uredinia surrounded by definite chlorotic areas. The susceptible seedlings had abundant uredinia without chlorosis. Tenmarq appeared to be segregating for resistance to physiologic form 3. Two pots of Tenmarq seedlings were inoculated with this form of leaf rust and

in both cases about 25 to 30 per cent of the seedlings were slightly resistant. Most seedlings of Minturki were susceptible although a few seedlings in each of the two pots showed some resistance. Seedlings of 32 F_3 lines were inoculated with physiologic form 9. Only six lines showed any signs of resistance. A small number of seedlings in these six lines showed moderate resistance while the most of them were very susceptible. Tenmarq was moderately susceptible and Minturki was very susceptible.

Physiologic forms 3 and 9 are forms commonly occurring in Kansas. On the basis of these observations it seems likely that the infection observed on the F_3 lines grown in the agronomy nursery in 1930 was caused by some physiologic form other than form 3 or 9.

The reaction of the F_4 lines inoculated with physiologic form 9 in the seedling stage in the greenhouse was much like the reaction obtained on the F_3 lines. Infection on all seedlings was described as type 4, very susceptible. The F_4 lines used in these seedling inoculation tests were selected from F_3 plants noted as resistant to leaf rust in the heading stage in the agronomy nursery in 1930. Tenmarq and Minturki were both susceptible to form 9.

Seedlings of the F_4 lines showed some resistance to physiologic form 15, as shown in the following tabulation:

	Class of infection					
	Res.	Medium Res.	Medium Sus.	Sus.	Seg.	Total
Number of F_4 lines....	2	8	25	104	9	148
Tenmarq.....	-	-	--	---	2	2
Minturki....	-	-	--	1	1	2

One of the F_4 lines in the resistant class showed a very high degree of resistance to this form of leaf rust. This same F_4 line was highly resistant to physiologic form 26 in the seedling stage and showed considerable resistance to leaf rust in the heading stage in the 1931 agronomy nursery. The reaction of the first and second leaves of a seedling from this resistant line and leaves of intermediate and susceptible F_4 seedlings are shown in Plate IV. First and second leaves of Tenmarq and Minturki are also shown in this plate. All of the seedlings from which these leaves were taken had been inoculated with physiologic form 15. Tenmarq also appeared to be segregating for resistance to form 15. All seedlings of Minturki in one of the pots were susceptible. The other pot contained a few very resistant seedlings. These very resistant seedlings probably represent mixtures of some other variety or natural hybrids. Physiologic form 15 is not a prevalent form of leaf rust in Kansas every year but is abundant in occasional seasons. This form of rust was found in the agronomy nursery in 1930.

Plate IV.-- Reaction of first and second leaves of Tenmarq, Minturki and of resistant and intermediate susceptible F_4 seedlings of Tenmarq x Minturki to leaf rust, Puccinia triticina, physiologic form 15. (2) Tenmarq parent, (b) resistant hybrid, (c) intermediate hybrid, (d) susceptible hybrid, (e) Minturki parent.

This may have been the form to which the F_3 lines were resistant in the heading stage in the 1930 agronomy nursery, though from the rust reaction of the seedlings it seems doubtful if this is the case.

The F_4 seedlings were more resistant to physiologic form 26 than to the other forms tested. More than half of the F_4 lines showed some type of resistance. The summary of the leaf rust reaction to form 26 is as follows:

	Res.	Medium Res.	Medium Sus.	Sus.	Seg.	Total
Number of F_4 lines....	1	40	20	59	26	146
Tenmarq.....	-	--	--	--	7	7
Minturki....	-	6	--	--	--	6

The same F_4 line noted as highly resistant to physiologic form 15 was also highly resistant to form 26. Unfortunately this line was discarded due to a high percentage of bunt. It is highly probable that the moderate resistant classes of seedlings will be highly resistant to this form of leaf rust at the heading stage in the field. Johnston and Melchers (26) found this condition to occur rather frequently among the common bread wheats. The high degree of resistance observed in the F_3 lines in the heading stage in the 1930 agronomy nursery would tend to indicate such a condition in these hybrids. Seedlings of Tenmarq in all seven pots planted were found to segregate for resistance to physio-

logic form 26. Approximately 30 per cent of the seedlings of Tenmarq were moderately resistant while the remainder were susceptible. Minturki was slightly resistant to this form of leaf rust. Physiologic form 26 is not a common form of leaf rust in Kansas. It was used in these inoculations because it was one of the forms found in the agronomy nursery in 1930.

Comparisons were made of the reactions of the F_3 and F_4 seedlings inoculated with different physiologic forms of leaf rust. There is very little evidence of clear cut correlations in the reaction to different forms. This is probably due to the fact that a large number of the seedlings were susceptible to several of the rust forms used. A summary of rust readings on F_3 and F_4 lines in the seedling stage in the greenhouse and in the heading stage in the nursery is presented in Table IV. All of the F_4 lines tested are not included in this table. Very little relationship exists between the leaf rust readings in the seedling stage in the greenhouse and the readings taken in the heading stage in the nursery. A comparison between the percentage of leaf rust infection recorded on the F_4 lines in the heading stage in the nursery and the infection recorded on the same lines inoculated with the seedling stage in the greenhouse with physiologic form 15 is shown in Table V. There is some relationship existing between the

Table IV.-- Reaction of F_3 and F_4 lines, Tenmarq x Minturki, to leaf rust, *Puccinia triticina*, in the seedling stage in the greenhouse and in the heading stage in the nursery.

Reaction of F_3 lines				Reaction of F_4 lines				
Pedigree No.	Seedling stage P. form 5	Seedling stage P. form 9	Heading stage 1930	Number of families	Seedling stage P. form 15	Seedling stage P. form 26	Seedling stage P. form 9	Heading stage 1931 (%)
6033-1	--	s	r	7	seg.	s	s	5-20
-2	s	seg.	s	--	---	--	--	--
-3	s	s	s	--	---	--	--	--
-6	s	s	r	8	seg.	seg.	s	10-20
-7	s	s	seg.	2	s	seg.	s	20
-9	seg.	s	seg.	7	seg.	seg.	s	15-25
-10	s	s	s	--	---	--	--	--
-11	s	s	s	--	---	--	--	--
-12	---	s	s	--	---	--	--	--
6034-1	s	s	---	--	---	--	--	--
-6	s	s	---	--	---	--	--	--
-8	s	s	---	--	---	--	--	--
-13	s	s	---	--	---	--	--	--
6035-3	---	s	---	--	---	--	--	--
-6	---	s	r	2	s	--	s	10-20
-7	seg.	s	seg.	1	s	--	s	20
-8	s	s	r	1	r	r	s	20
-11	s	seg.	r	6	s	seg.	s	15-25
-12	s	seg.	s	--	---	--	--	--
6036-1	---	s	r	8	s	seg.	s	20-40
-6	seg.	s	seg.	2	s	r	s	35
-7	s	s	seg.	1	s	r	s	30
-10	seg.	s	seg.	2-3	seg.	r	s	25-30
-13	seg.	s	seg.	1	s	r	s	25
-14	s	s	seg.	5	seg.	seg.	s	20-25
-15	s	seg.	r	8	s	seg.	s	15-25
-17	seg.	s	seg.	2	s	r	s	10-25
6037-4	s	s	r	6	seg.	seg.	s	10-25
-5	---	s	r	10	s	s	s	25-30
-8	seg.	s	seg.	3	seg.	seg.	s	25-30
-14	s	seg.	r	10	s	seg.	s	25-40
-18	---	seg.	r	7	s	seg.	s	10-25
Tenmarq	seg.	s	r	--	s	r	s	15-60
Minturki	seg.	s	s	--	s	seg.	s	20-40

Table V.— Leaf rust reaction of F_4 lines of Tenmarq x Minturki to physiologic form 15 in the seedling stage in the greenhouse and heading stage in the field.

Leaf rust infection in heading stage in the field (Per cent)	Reaction of seedlings in the greenhouse				
	Resistant (10%)	Medium resistant (20%)	Medium susceptible (30%)	Susceptible (40%)	Average per cent infection
5	---	---	---	1	40.0
10	1	4	4	8	31.2
15	---	2	8	9	33.7
20	1	---	4	33	38.2
25	---	2	7	26	34.9
30	---	---	1	20	39.5
35	---	---	1	4	38.0
40	---	---	---	3	40.0

two sets of readings. Lines highly resistant in the seedling stage in the greenhouse are also resistant in the heading stage in the nursery. A similar comparison between the reaction of the F_4 lines to form 26 in the seedling stage in the greenhouse and the amount of leaf rust infection recorded on the same F_4 lines in the heading stage in the 1951 agronomy nursery is shown in Table VI. The relationship between these two readings is not so close as when form 15 was compared with the field reading in the heading stage. In order to determine an average percentage of infection the resistant seedlings were considered to have an infection of 10 per cent, the more or less resistant class was given a reading of 20 per cent and so on. The segregating lines were not included in the comparison. The comparison between the rust reaction of the F_4 lines in the seedling stage to form 15 and heading stage in the nursery is shown graphically in Figure 2. A similar comparison for leaf rust form 26 is shown graphically in Figure 3.

Reaction of Hybrids to Bunt

A composite of physiologic forms of bunt collected in Kansas was used in inoculating the F_3, F_4, F_5 and F_6 lines. This inoculum was obtained from the Department of Botany. Each hybrid line planted represented a single plant selection from the previous generation. F_3 and F_4 lines with

Table VI.-- Reaction of F_4 lines, Tenmarq x Hinturki to physiologic form 26 in the seedling stage in the greenhouse and in the heading stage in the field.

Leaf rust infection in heading stage in the field (Per cent)	Reaction of seedlings in the greenhouse				
	Resistant (10%)	Medium resistant (20%)	Medium susceptible (30%)	Susceptible (40%)	Average per cent infection
5	---	---	---	1	40.0
10	1	6	1	3	25.5
15	---	5	---	7	31.7
20	---	8	---	17	33.6
25	---	8	1	17	33.5
30	---	7	---	10	31.8
35	---	3	---	1	25.0
40	---	1	---	2	33.3

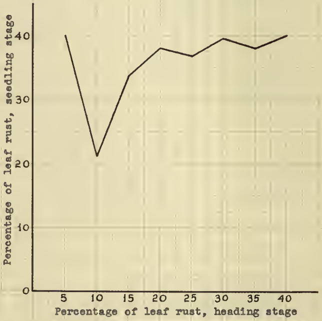


Fig. 2.-- Percentage of leaf rust of F_4 lines inoculated with physiologic form 15 in the seedling stage in the greenhouse and in the heading stage in the field.

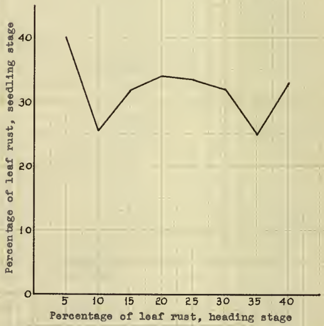


Fig. 3.-- Percentage of leaf rust on F_4 lines of Tenmarq x Minturki inoculated with physiologic form 26 in the seedling stage in the greenhouse and in the heading stage in the field.

parental checks were planted in the botany nursery in the fall of 1930. Each hybrid progeny was space-planted in a single rod row. The rows were one foot apart and the seed was spaced approximately four inches apart in the rows. The F_3 lines planted in the botany nursery in the fall of 1930 were from remnant seed of the F_3 lines planted in the agronomy nursery in the fall of 1929. The F_4 lines selected from F_3 plants resistant to leaf rust were also planted in the botany nursery in the fall of 1930. Neither the F_2 nor the F_3 generations which produced the F_3 and F_4 lines had been inoculated with bunt. The F_5 generation consisted of individual plant selections from bunt-free F_4 lines.

The percentages of bunted plants of 31 F_3 lines inoculated with a Kansas composite of physiologic forms of bunt are as follows:

Percentage of bunted plants

	0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	Total	Av. infection
Number of F_3 lines..	1	9	2	7	8	4	--	--	31	11.8
Tenmarq...	-	-	-	-	3	2	4	1	10	24.5
Minturki..	1	8	-	-	-	-	--	--	9	2.2

Ten F_3 lines were as resistant to bunt as Minturki. The average per cent infection of the hybrids is between the averages of Tenmarq and Minturki. The hybrids appear to be

divided into two groups, (a) resistant lines with 0 to 5 per cent bunt and (b) susceptible lines with more than 10 per cent bunt. Ten F_3 lines showed less than 5 per cent bunt. There were only two lines having between 6 and 10 per cent infection. The remainder of the hybrids had over 10 per cent infection. The number of lines involved is far too small to attempt any detailed analysis of the factorial basis of bunt resistance in this cross. Many of the hybrid lines were much more resistant to bunt than Tenmarq. A frequency distribution of the bunt infection of the hybrids is shown graphically in Figure 4.

A large number of bunt-free and low bunt lines were obtained in the F_4 generation although the F_2 and F_3 generations which produced this F_4 generation had not been inoculated with bunt. The following results were obtained in F_4:

Percentage of bunted plants

	0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	Total	Av. infection
Number of F_4 lines..	12	23	22	26	29	19	10	4	1	2	148	14.0
Tenmarq...	-	-	-	-	3	2	4	1	-	-	10	24.5
Minturki..	1	8	-	-	-	-	-	-	-	-	9	2.2

In the population of 148 F_4 lines there were three containing a higher percentage of bunt than the most susceptible row of Tenmarq. In the F_3 generation of only 31 lines there

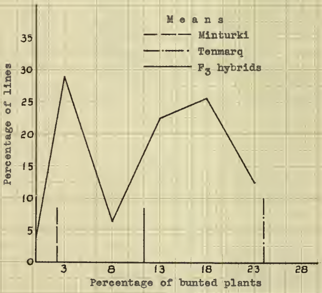


Fig. 4.-- Percentage of bunted plants in F_3 lines of Tenmarq x Minturki, botany nursery, 1931.

were none as susceptible as the most susceptible row of Tenmarq. The F_3 and F_4 lines were all planted at the same time and under the same conditions. The same inoculum was used on the F_3 and F_4 lines. The results obtained in the F_3 and F_4 generations indicate the presence of multiple factors determining reaction to bunt in this cross. Recombinations occurred in F_4 that appeared to be more susceptible than Tenmarq to bunt. It is reasonable to expect also that some of the bunt-free lines observed in F_4 may be more resistant than Minturki. A distribution of the F_4 lines is shown graphically in Figure 5. The infection percentages of the F_4 hybrids have a tendency to form a bimodal curve, though this tendency is not so distinct as the bimodal curve formed by the F_3 lines. The percentages of bunted plants in the F_3 and F_4 lines and in the parents are given in Table VII.

F_4 lines from F_3 lines of low bunt infection tended to have a low percentage of bunt. The F_3 lines are grouped in quartiles according to per cent bunted plants in Table VIII. The bunt percentages of the F_4 lines are shown opposite the F_3 lines from which they came. The quartile averages are as follows:

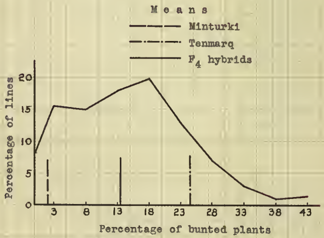


Fig. 5.-- Percentage of bunted plants in F_4 lines of Tenmarq x Minturki, botany nursery, 1931.

Table VII.-- Percentages of bunted plants in F_3 and F_4 lines of Tenmarq x Minturki and parents.

Botany nursery, 1931.

Percentage of bunted plants	F_3 lines		F_4 lines		Tenmarq		Minturki	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
0..........	1	3.2	12	8.1	--	--	1	11.1
1-5........	9	29.0	23	15.5	--	--	8	88.9
6-10.......	2	6.5	22	14.9	--	--	--	--
11-15......	7	22.6	26	17.6	--	--	--	--
16-20......	8	25.8	29	19.6	3	30.0	--	--
21-25......	4	12.9	19	12.8	2	20.0	--	--
26-30......	--	--	10	6.8	4	40.0	--	--
31-35......	--	--	4	2.7	1	10.0	--	--
36-40......	--	--	1	.7	--	--	--	--
41-45......	--	--	2	1.4	--	--	--	--
Total......	31	--	148	--	10	--	9	--
Average....	--	11.5	--	15.6	--	24.0	--	2.2

Table VIII.— Percentage of bunted plants in F_3 and F_4 lines of Tenmarq x Minturki inoculated with a composite of Kansas collection of bunt.

Botany nursery, 1931.

1930 Row No.	Percentage of bunt F_3 lines	Percentage of bunt by classes, F_4 lines										Av. percentage of bunt by quartiles	
		0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	F_3 lines	F_4 lines
Quartile I													
5078	2	-	-	--	--	--	--	--	--	--	--	---	---
5072	3	-	-	--	--	--	--	--	--	--	--	---	---
5073	3	-	-	--	--	--	--	--	--	--	--	---	---
5079	3	-	-	--	--	--	--	--	--	--	--	---	---
5071	5	1	-	5	--	--	1	--	--	--	--	---	---
5075	5	-	-	--	--	--	--	--	--	--	--	---	---
5076	7	3	2	2	1	--	--	--	--	--	--	---	---
	-	-	-	--	--	--	--	--	--	--	--	4.0	6.5
Quartile II													
5077	8	-	1	1	5	1	--	1	--	--	--	---	---
5103	12	-	1	2	1	2	2	--	--	--	--	---	---
5095	13	-	-	--	--	--	--	--	--	--	--	---	---
5098	13	-	-	--	--	--	1	--	--	--	--	---	---
5101	13	-	-	--	--	--	--	1	--	--	--	---	---

Table VIII (concluded)

5104	15	-	-	--	1	1	--	--	--	--	--	---	---
4097	14	--	-	--	--	--	--	2	--	--	--	---	---
	-	-	-	--	--	--	--	--	--	--	--	16.3	16.9
Quartile III													
5099	15	-	-	--	2	--	1	--	--	--	--	---	---
5096	16	-	-	--	1	3	3	1	--	--	--	---	---
5095	17	-	-	1	--	--	--	--	--	--	--	---	---
5089	18	-	-	--	--	--	--	--	--	--	--	---	---
5094	18	-	-	1	2	3	1	--	1	--	--	---	---
5091	19	-	-	--	--	1	1	--	--	--	--	---	---
5092	19	-	-	--	--	1	--	--	--	--	--	---	---
	-	-	-	--	--	--	--	--	--	--	--	17.4	18.4
Quartile IV													
5108	19	-	-	1	3	4	1	--	--	1	--	---	---
5102	20	-	-	-	-	-	1	3	1	--	--	---	---
5106	22	-	-	1	2	5	2	--	--	--	--	---	---
5107	22	-	-	-	-	1	1	1	--	--	--	---	---
5100	25	-	-	-	-	2	2	--	1	--	2	---	---
5105	28	-	-	-	2	3	1	1	1	--	--	---	---
	-	-	-	-	-	--	--	--	--	--	--	21.8	21.6
Total	-	4	4	14	18	27	18	10	4	1	2	---	---

Average percentage of bunted plants

Quartiles	F_3 lines	F_4 lines
1	4.0	6.5
2	12.3	16.5
3	17.4	18.4
4	21.8	21.5

There is a very definite correlation between the amount of bunt observed in the F_3 lines and the amount of bunt in the F_4 lines derived from them. As the percentage of bunt increased in the F_3 lines there was also an increase in the amount of bunt found in the F_4 progenies of these lines.

The individual plants saved for growing the F_5 generation were selected from the twelve F_4 lines which showed no bunt infection. The F_4 lines inoculated with bunt and grown in the botany nursery at Manhattan in 1931 were also grown at Akron, Colo., Colby, Kan., and in the agronomy nursery at Manhattan. Desirable F_4 plants grown at each of these stations were selected from bunt-free lines, as determined in the botany nursery, for growing the F_5 generation. The percentages of bunt, based on the number of bunted heads per row, of the F_5 lines inoculated with bunt and planted in the botany nursery in the fall of 1931 and harvested in 1932 are shown in Table IX. The average percentages of bunted heads in the hybrid lines and parental check rows are as follows:

Table IX.— Percentages of bunted heads in F_5 lines of Tenmarq x Minturki from bunt-resistant F_4 lines.

Botany nursery, 1932.

Percentage of bunted heads	F_5 lines		Tenmarq		Minturki	
	Number	Per cent	Number	Per cent	Number	Per cent
0	22	14.9	---	---	2	22.2
1-5..........	103	69.6	---	---	6	66.7
6-10........	19	12.8	---	---	1	11.1
11-15.......	3	2.0	---	---	---	---
16-20.......	1	.7	---	---	---	---
21-25.......	---	---	2	22.2	---	---
26-30.......	---	---	---	---	---	---
31-35.......	---	---	---	---	---	---
36-40.......	---	---	---	---	---	---
41-45.......	---	---	---	---	---	---
46-50.......	---	---	---	---	---	---
51-55.......	---	---	3	33.3	---	---
56-60.......	---	---	---	---	---	---
61-65.......	---	---	---	---	---	---
66-70.......	---	---	2	22.2	---	---
71-75.......	---	---	1	11.1	---	---
90-95.......	---	---	1	11.1	---	---
Totals......	148	---	9	---	9	---
Averages....	---	3.0	---	55.7	---	2.3

Average percentage of bunted heads

F_5 lines 3.1
Tenmarq 56.7
Minturki 2.3

The F_5 lines had an average bunt infection only slightly higher than the average bunt infection of Minturki. Only 23 of the 148 F_5 lines grown in 1932 from bunted seed showed more than 5 per cent bunted heads. There were 22 bunt-free F_5 lines. The distribution of the bunt infection of 148 F_5 lines is shown graphically in Figure 6.

Tenmarq had a much higher infection of bunt in 1932 than in 1931. The high percentage of bunt on Tenmarq in 1932 indicates that a very good infection of bunt was obtained and that hybrid lines with zero or low bunt infection are really resistant.

The value of the pedigree method of plant breeding is definitely shown in these studies of bunt resistance. Individual plant selection for bunt resistance in only one generation has given rise to an F_5 population with an average percentage of bunt infection only slightly higher than that of Minturki, the resistant parent.

There appeared to be a preponderance of types with many of the undesirable plant characters of Minturki, the bunt resistant parent. Very few of the bunt resistant types had the desirable characteristics of Tenmarq. The

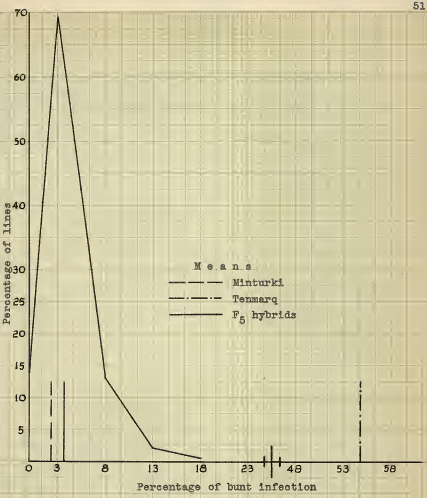


Fig. 6.-- Percentage of bunted plants in F_5 lines of Tenmarq x Minturki, from bunt-free F_5 lines, botany nursery, 1932.

factors for long, lax heads, leafiness and lateness received from Minturki were present in most of the bunt-resistant hybrids.

Comparison of Leaf Rust Reaction and Bunt Reaction

The leaf rust readings taken on the F_3 lines grown in the botany nursery and the percentage of bunt recorded on the same lines were compared. In the material used there appears to be no consistent relationship between these two characters. The percentage of bunt occurring in F_3 lines did not increase or decrease with increased susceptibility to leaf rust. A frequency distribution comparing the rust and bunt reactions of the F_3 lines is presented in Table X. The correlation between the percentages of leaf rust and bunt was determined by the following formula where

$$r = \frac{\frac{\Sigma xy}{N} - (\bar{x})\ (\bar{y})}{\sqrt{\frac{\Sigma x^2}{N} - (\bar{x})^2}\ \sqrt{\frac{\Sigma y^2}{N} - (\bar{y})^2}} \qquad \text{and P.E.} = \pm\ \frac{.6745\ (1-r^2)}{\sqrt{N}}$$

The value of r was found to be $-.2250 \pm .1696$. There is a slight negative correlation between rust and bunt infection percentages, but the value of r has no statistical significance and certainly no practical significance.

The leaf rust notes taken on the F_4 lines grown in the agronomy nursery in 1931 were compared with the percentage of bunt occurring on the same lines grown in the botany

Table X.-- Correlation between leaf rust reaction in the heading stage and percentage of bunt of F_3 lines, Tenmarq x Minturki.

Botany nursery, 1931.

Leaf rust Per cent	Per cent bunted plants 0	1-5	6-10	11-15	16-20	21-25	Average bunt infection Per cent
30....	-	2	---	---	---	---	2.5
35....	-	---	---	---	---	---	---
40....	-	---	---	---	---	---	---
45....	-	---	---	1	1	---	15.5
50....	-	1	---	1	6	2	17.0
55....	-	---	---	---	---	---	---
60....	-	1	1	4	1	---	11.5
65....	-	5	1	2	---	---	5.8
70....	1	---	---	---	---	1	11.5

$r = -.2250 \pm .1696$

nursery. The comparison between reactions to these two diseases is shown in Table XI. The classes of low leaf rust infection show slightly lower bunt infection. The differences in amount of bunt infection in the high and low leaf rust classes are not great enough to be of much practical significance. The correlation between percentages of leaf rust and bunt in the F_4 lines was determined. The value of r was found to be .4707 ± .0432. This value is statistically significant but is not large enough to have a great significance in practical plant breeding.

Relative Winter Hardiness

Winter survival percentages were determined on the F_2, F_3 and F_4 generations of this cross. The hybrids were grown in space-planted nursery rows one foot apart. The seeds were spaced approximately 4 inches apart in the rows. Individual plant counts were made in the fall and again in the spring. The percentages of plants surviving are used as an index of winter hardiness.

The winter survival of the six F_2 populations, each from an individual F_1 plant, varied from 88.8 per cent to 100 per cent. Tenmarq had an average winter survival of 87.5 per cent and Minturki 100 per cent. Very little winterkilling occurred during the winter of 1928-'29 at Manhattan, but the difference in survival of Tenmarq and Minturki is in

Table XI.-- Correlation between leaf rust reaction of F_4 lines of Tenmarq x Minturki in the heading stage grown in the agronomy nursery, and the percentage of bunt in the same lines grown in the botany nursery.

Manhattan, Kansas, 1931.

Leaf rust Per cent	0	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	Average bunt infection Per cent
tr-14...	2	3	2	3	5	3	1	1	--	--	13.7
15-24...	7	15	13	6	7	4	3	2	--	--	10.4
25-34...	2	5	7	15	16	11	4	1	1	2	16.8
35-44...	1	--	--	--	3	1	2	--	--	--	19.0

$r = .4707 \pm .0432$

line with other tests of these two varieties.

Winter survival percentages were determined on 36 F_3 lines grown in the agronomy nursery in 1930, and 31 F_3 lines grown in the botany nursery in 1931. Estimated winter survival percentages were determined on 33 F_3 lines grown at Colby in 1930. These lines were not space-planted making it impossible to count the number of plants per row and to determine the percentage of survival as at Manhattan. Estimates of survival instead of actual percentages of survival were used at Colby.

The winter survival of the F_3 lines grown at Manhattan in 1930 varied from 80 to 100 per cent, averaging 94.3 per cent. Tenmarq had an average winter survival of 93.3 per cent and Minturki 95 per cent. The winter of 1929-'30 at Manhattan was not severe enough to cause any great amount of winterkilling. The high per cent survival of the hybrids gives no assurance that they are exceptionally hardy, since Tenmarq, a variety known to be only moderately cold resistant, also has a high survival.

At Colby under more adverse conditions the F_3 lines had an average estimated survival of 63.6 per cent. Not all of the winterkilling at Colby in 1929-'30 is thought to be due to low temperatures. Other factors such as soil blowing and low moisture content of the soil are thought to be partly

responsible. The winter survival notes taken at Colby are as follows:

Per cent winter survival (estimated)

	5	15	25	35	40	50	60	70	75	80	85	90	Total	Average survival Per cent
Number of F_3 lines,	1	1	1	2	2	4	3	4	2	5	5	3	33	63.6
Tenmarq..	1	-	-	-	-	-	-	-	-	-	-	-	1	5.0
Minturki,	-	-	-	-	-	-	-	1	-	-	-	-	1	70.0

The winter survival estimates of Tenmarq and Minturki are based on only one row of each variety. The very low survival of the Tenmarq row is probably not representative of the variety as Tenmarq in other plantings at Colby in 1929-'30 had a much higher winter survival. Minturki, which is known to be a very winter hardy variety, had a winter survival of only 70 per cent. Many of the hybrid lines in this nursery test appear to be more winter hardy than Minturki, but the significance of this difference can only be determined by further tests.

There was almost 100 per cent winter survival of F_3 lines planted in the botany nursery in the fall of 1930. Tenmarq and Minturki also showed very little winterkilling.

F_4 lines selected from F_3 plants noted as resistant to leaf rust in the heading stage were planted at Manhattan and Colby, Kan., Akron, Colo., and North Platte, Nebr., to obtain data on winter hardiness. One hundred and forty-nine

F_4 lines were planted at all of these stations except at Akron where only 100 lines were planted.

Mr. N. E. Jodon of the North Platte station states that there was no killing among the F_4 lines planted at North Platte. The winter of 1930-'31 was very mild at Colby and very little winterkilling occurred.

At Akron, Colo., some winterkilling occurred in 1930-'31. The F_4 lines had an average winter survival of 91.6 per cent. Tenmarq had an average survival of 87.5 per cent and Minturki 91 per cent. The winter survival notes taken at Akron are as follows:

	Per cent winter survival											Total	Average survival Per cent
	50	55	60	65	70	75	80	85	90	95	100		
Number of F_4 lines..	1	1	0	0	1	3	9	6	22	30	27	100	91.6
Tenmarq...	-	-	-	-	1	1	-	-	1	2	1	6	87.5
Minturki..	-	-	-	-	-	-	-	2	-	3	-	5	91.0

The results indicate that many of the hybrid lines are as winter hardy as Minturki although the average differences are too small to be of much practical significance.

The F_4 lines planted in the botany nursery in the fall of 1930 had an average winter survival of 99.2 per cent, Tenmarq and Minturki having survivals of 99.4 and 98.1 per cent, respectively. The winter survival of the F_4 lines planted in the agronomy nursery in the fall of 1930 was about the same as in the botany nursery.

Very little definite information as to the relative winter hardiness of the hybrids as compared to Tenmarq and Minturki has been obtained. At Colby in 1930 when considerable winterkilling occurred the hybrid lines appeared to be more winter hardy than Tenmarq and many showed a higher percentage of survival than Minturki. At Akron, Colo., in 1931, the hybrids had as high an average winter survival as Minturki. These are the only stations where any information as to the relative winter hardiness of the hybrids and parental varieties has been obtained. Further testing is necessary before any definite conclusions can be drawn as to the relative winter hardiness of these hybrids.

Date of First Heading

The date of heading as reported in this paper represents the date when the first few heads in each row emerged from the boot. Heading dates of individual plants would have been a much more reliable index of earliness in the segregating generations, but it was impossible to secure these data. However, these heading dates on a row basis give an indication as to the relative earliness of the hybrids as compared to the parents.

Plants in the F_2 populations grown in space-planted nursery rows had an average first heading date of May 30. Tenmarq had an average first heading date of May 29 and

Minturki an average first heading date of June 3. The hybrid rows were fully headed a little earlier than Minturki.

The first heading dates taken on the F_3 lines grown in the Agronomy nursery in 1930 were as follows:

Date first headed

	May												June		To-	Av.
	20	21	22	23	24	25	26	27	28	29	30	31	1	2	tal	date
Number of F_4 lines,	1	1	0	0	5	3	6	3	11	4	0	1	1	0	36	5/27
Tenmarq..	-	-	-	-	-	-	-	-	-	1	1	1	-	-	3	5/30
Minturki,	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2	6/2

The average first heading date of the F_3 lines grown in the agronomy nursery in 1930 is three days earlier than the average first heading date of Tenmarq. All of the hybrid rows started to head before Minturki. The last plants to head in the hybrid rows headed about one day earlier than the last plants to head in the Minturki check rows. The first heading dates of the F_3 lines grown in 1930 are shown graphically in Figure 7.

The first heading dates were also recorded on the F_3 lines grown in the botany nursery in 1931. The average first heading date of the hybrids falls between the average first heading dates of the parents. Tenmarq averages five days earlier than Minturki. The hybrids are mostly later than Tenmarq. The first heading dates on the F_3 lines grown in the botany nursery are as follows:

Date first headed

	May						June					Total	Average date
	26	27	28	29	30	31	1	2	3	4	5		
Number of F_3 lines,	1	0	9	4	3	4	7	1	0	1	1	31	5/30
Tenmarq..	-	2	-	-	-	-	-	-	-	-	-	2	5/27
Minturki,	-	-	-	-	-	1	1	-	-	-	-	2	6/1

There appear to be two classes of lines in this group, one group that heads just a little later than Tenmarq and another group that heads about the same time as Minturki. This is shown graphically in Figure 8. The last plants to head in the hybrid rows headed about the same time as the last plants in the Minturki rows. Tenmarq was fully headed several days earlier than the hybrids.

The first heading dates recorded on the F_4 lines grown in the agronomy nursery are as follows:

Date first headed

	May						Total	Average date
	19	25	26	27	28	29		
Number of F_4 lines...	1	14	67	4	36	27	149	27
Tenmarq....	-	3	5	-	--	--	8	26
Minturki...	-	--	--	-	1	7	8	29

The hybrids averaged one day later in heading than Tenmarq. They averaged two days earlier than Minturki. These data on comparative earliness of parents and hybrids are shown graphically in Figure 9. Most of the hybrids were fully headed about the same time as Minturki. Tenmarq was fully

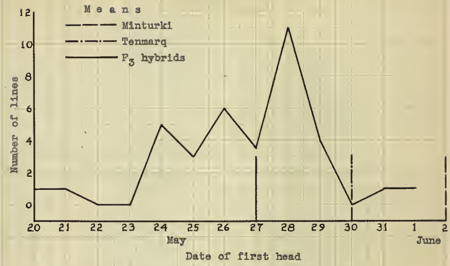


Fig. 7.-- First heading dates, F_3 lines of Tenmarq x Minturki, agronomy nursery, 1930.

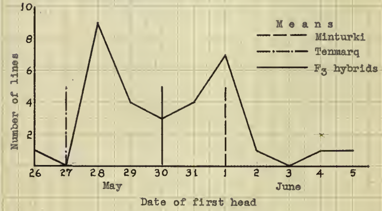


Fig. 8.-- First heading dates, F_3 lines of Tenmarq x Minturki, botany nursery, 1931.

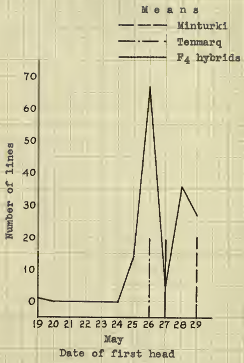


Fig. 9.-- First heading dates, F_4 lines of Tenmarq x Minturki, agronomy nursery, 1931.

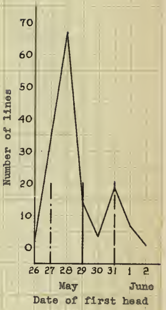


Fig. 10.-- First heading dates, F_4 lines of Tenmarq x Minturki, botany nursery, 1931.

headed several days ahead of the hybrids. Although there were a few early plants in each row the majority of the hybrid plants resembled Minturki not only in time of heading but also in other characters.

The F_4 lines grown in the botany nursery headed in about the same order as the F_4 lines grown in the agronomy nursery. The hybrids in the botany nursery had an average first heading date two days earlier than Minturki and two days later than Tenmarq. The date fully headed of the hybrids was in most cases later than the date of full heading for Tenmarq. The first heading dates of the F_4 lines grown in the botany nursery are as follows:

Date first headed

	May						June			Average
	26	27	28	29	30	31	1	2	Total	date (May)
Number of F_4 lines..	3	34	67	14	4	19	7	1	149	29
Tenmarq...	2	6	--	--	-	--	-	-	8	27
Minturki..	-	--	1	1	-	4	2	-	8	31

The F_4 lines planted in the botany nursery were planted late to secure optimum conditions for bunt infection. This accounts for the later heading dates in this nursery. First heading dates on the F_4 lines grown in the botany nursery are shown graphically in Figure 10.

At Colby, Kan., a wider range between the first heading dates of the different F_4 lines was observed. However,

most of the hybrids headed between the average heading dates of the two parents. The first heading dates of the F_4 lines grown at Colby are as follows:

	Date first headed													
	May			June										Average
	29	30	31	1	2	3	4	5	6	7	8	9	Total	date
Number of F_4 lines,	1	17	7	38	30	33	22	0	2	1	-	-	149	6/2
Tenmarq..	-	4	0	3	0	0	1	-	-	-	-	-	8	5/31
Minturki,	-	--	-	-	1	1	3	-	1	-	-	2	8	6/5

The average first heading date of the hybrids is two days later than the average first heading date of Tenmarq and three days earlier than the average first heading date of Minturki. Tenmarq was fully headed earlier than most of the hybrids. The last plants to head in a large number of the hybrid rows were as late in heading as the last plants to head in the Minturki rows. The lateness of the hybrids planted at Colby was a serious handicap. Most of the plants dried up before they were fully mature. The first heading dates of the F_4 lines grown at Colby are shown graphically in Figure 11.

The F_4 lines grown at Akron, Colo., form a frequency curve, for date of first heading, very similar to the curve formed by the F_4 lines grown at Colby. The frequency distribution of the first heading dates of the F_4 lines grown at Akron is shown in Figure 12. The first heading dates of the hybrids average one day later than Tenmarq and four days

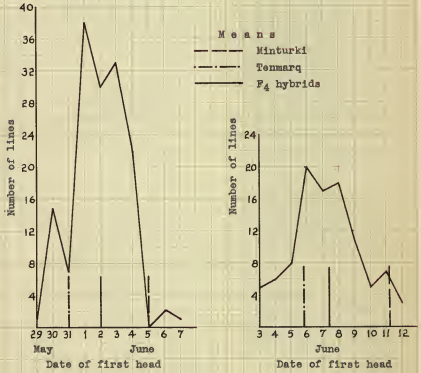


Fig. 11.-- First heading dates of F_4 lines of Tenmarq x Minturki, Colby, Kansas, 1931.

Fig. 12.-- First heading dates of F_4 lines of Tenmarq x Minturki, Akron, Colorado, 1931.

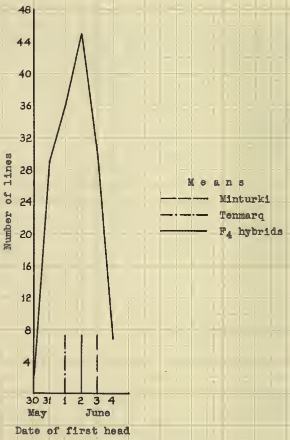


Fig. 13.-- First heading dates of F_4 lines of Tenmarq x Minturki, North Platte, Nebraska, 1931.

earlier than Minturki. The first heading dates recorded at Akron are as follows:

Date first headed

	June											
	3	4	5	6	7	8	9	10	11	12	Total	Average date
Number of F_4 lines..	5	6	8	20	17	18	11	5	7	3	100	7
Tenmarq...	-	1	1	3	1	--	--	-	-	-	6	6
Minturki..	-	-	-	--	-	--	--	-	4	1	5	11

Many of the F_4 lines appeared to be fairly well adapted to Akron conditions. The last plants to head in the hybrid rows planted at Akron headed about the same time the last plants headed in the Tenmarq rows. Nearly all the hybrid rows were fully headed earlier than Minturki.

The first heading dates on the F_4 lines grown at North Platte, Nebr., are shown in the following table:

Date first headed

	May		June					
	30	31	1	2	3	4	Total	Average date (June)
Number of F_4 lines....	2	29	36	45	30	7	149	2
Tenmarq.....	-	3	4	1	--	-	8	1
Minturki....	-	--	--	--	5	3	8	3

The hybrids average one day later in heading than Tenmarq and one day earlier than Minturki. Only one heading date was taken on the F_4 lines grown at North Platte. The range of the heading period of the hybrids is not so wide as at other stations. The frequency distribution of the first heading dates of the F_4 lines grown at North Platte is shown

in Figure 13.

The F_4 lines of this cross were earlier in heading than Minturki. There were very few F_4 lines as early as Tenmarq. In selecting the F_3 plants for growing the F_4 lines the earliest maturing plants were saved. There appears to be a preponderance of the Minturki characteristics in the hybrid lines. Although the earliest types were saved each year the average first heading date of the F_4 lines is later than the average first heading date of Tenmarq. This was true at all of the stations where the F_4 lines were grown. The F_4 lines appeared more promising at Akron than at any other station. The hybrids headed more nearly at the time Tenmarq headed than at the other stations.

The hybrids averaged much later in date of full heading than Tenmarq. The last plants to head in the hybrid rows were but very little ahead of the last plants to head in the Minturki rows. Due to the lateness of most of the hybrids the possibility of obtaining a desirable wheat for Kansas is not very great. The hybrids had a strong tendency to resemble Minturki in characters other than earliness, such as height and leafiness of plants, and length of head.

Plant Height

Under most conditions plants of Minturki are taller than Tenmarq. Since there is a difference in the height of

the two parents the hybrids produced from a cross between these varieties should show considerable variation in height.

The height of the six F_1 plants grown in the greenhouse during the winter of 1927-'28 averaged 20 inches. Plants of Tenmarq and Minturki grown under the same conditions measured 18 and 22 inches, respectively.

The height of the plants in each row in the nursery was determined by taking an average measurement of height of the plants in the row. The average height of the plants in the F_2 population was about 44 inches. Plants of Minturki in adjacent rows measured 45 inches. Plants in the nearest Tenmarq row measured 47 inches in height, which is somewhat taller than usual for this variety. This row of Tenmarq was grown some distance from the F_2 hybrids and is not strictly comparable with them.

Data on the plant height of the F_3 lines and parents grown in the agronomy nursery in 1930 are as follows:

Height in inches

	38	39	40	41	42	43	44	45	Total	Average height
Number of F_3 lines...	1	1	12	12	8	1	1	--	36	40.9
Tenmarq....	1	-	2	--	-	-	-	--	3	39.3
Minturki...	-	-	--	--	-	-	-	1	2	44.0

The mean height of the hybrids falls between the mean height

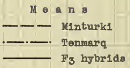
of the two parents. A large number of the hybrids fall in the same class as the Tenmarq parent. The distribution of the heights of these F_3 lines is shown graphically in Figure 14.

The F_3 lines grown in the botany nursery in 1931 reacted differently with respect to height of plant. The average height of the hybrids was slightly less than the average height of Tenmarq. This is shown in the following table:

Plant height in inches

	38	39	40	41	42	43	44	55	Total	Average height
Number of F_3 lines...	1	1	2	6	11	4	6	0	31	42.0
Tenmarq....	-	-	-	-	1	1	-	-	2	42.5
Minturki...	-	-	-	-	-	1	-	1	2	44.0

Since only two rows of each parental variety were measured there is some doubt as to how much weight to give to the average height of the two parents. They are, however, in about the usual relation. A possible explanation for the shortness of the hybrids is the very late planting of this material. This late planting, causing the hybrids to ripen later than in the previous year, may also account for the shorter plant height. The data on plant height of the F_3 lines grown in the botany nursery in 1931 are shown graphically in Figure 15.



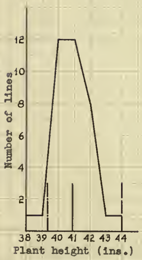


Fig. 14.-- Plant height in inches, F_3 lines of Tenmarq x Minturki, agronomy nursery, 1931.

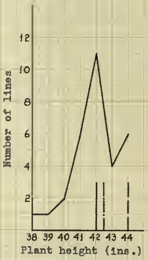


Fig. 15.-- Plant height in inches, F_3 lines of Tenmarq x Minturki, botany nursery, 1931.

The data on plant height of the F_4 lines grown at Akron, Colo., in 1931 are as follows:

Plant height in inches

	26	27	28	29	30	31	32	33	Total	Average height
Number of F_4 lines...	6	15	18	15	17	12	10	7	100	29.3
Tenmarq....	-	--	1	1	3	1	--	-	6	29.7
Minturki...	-	--	2	-	2	-	--	1	5	29.8

The average height of the F_4 lines is almost the same as the average height of Tenmarq and Minturki. A probable explanation for the failure of Minturki to show its greater height is that the semi-arid conditions prevailing at Akron did not allow the factors for tallness to be expressed in as definite a manner as under more favorable conditions. The hybrids had a tendency to resemble Minturki in leafiness and other morphological characters and were affected in a similar manner. The data on plant height recorded at Akron in 1931 are shown graphically in Figure 16.

Under more favorable conditions at Manhattan the F_4 lines showed a wider range in height varying from 38 to 48 inches, as shown in the following table:

Plant height in inches

	38	39	40	41	42	43	44	45	46	47	48	Total	Av. height
Number of F_4 lines,	1	3	8	20	18	20	27	30	10	9	3	149	43.5
Tenmarq.,	-	-	-	1	4	2	--	1	--	-	-	8	42.5
Minturki,	-	-	-	-	-	-	1	3	2	2	-	8	45.6

There are lines taller than Minturki and lines shorter than Tenmarq. The average plant height of the F_4 lines is between the averages of the parents. A large number of lines were about the same height as Tenmarq, though the modal class of the hybrids approaches Minturki. By selecting individual plants the height of Tenmarq, in previous generations, a large number of lines of about this height have been obtained. The data on height of the F_4 lines and parents grown at Manhattan are shown graphically in Figure 17.

Relation of Plant Height and Date of First Heading

Plant height and date of first heading were compared in the F_3 and F_4 lines of the cross Tenmarq x Minturki. In the F_3 lines grown in the agronomy nursery in 1930 no consistent relationship between plant height and time of first heading was observed. The hybrids were arranged in order of earliness and divided into four classes. The averages for plant height of the four groups are as follows:

Average date first head (May)	Number of lines	Average plant height (Inches)
23	9	40.1
26	10	41.6
28	11	40.7
30	6	41.8

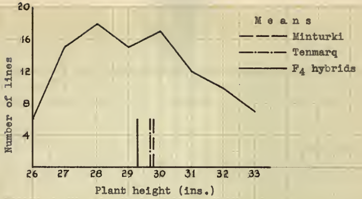


Fig. 16.-- Plant height in inches, F_4 lines of Tenmarq x Minturki, Akron, Colorado, 1931.

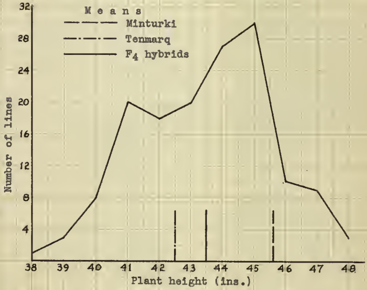


Fig. 17.-- Plant height in inches, F_4 lines of Tenmarq x Minturki, agronomy nursery, Manhattan, Kansas, 1931.

The F_3 lines grown in the botany nursery in 1931 were arranged in order of first heading and divided into four classes. There was no close association between plant height and time of first heading in this material. The very late lines were slightly taller than the earlier classes. However, the earliest lines were nearly as tall as the latest lines. Plants of lines in the intermediate classes, in heading date, were the shortest. This variation is probably due to chance. The average first heading dates and plant height measurements of the different classes are as follows:

Average date first head	Number of lines	Average plant height (Inches)
May 28	10	42.1
May 29	7	41.7
May 31	6	41.0
June 2	9	42.8

The F_4 lines grown in the agronomy nursery in 1931 showed no consistent relationship between plant height and date of first heading. The hybrids placed in four classes according to plant height had the same average first heading dates in the different classes.

Plant height and date of first heading were also compared on the F_4 lines grown at Akron, Colo., in 1931. When the lines were placed in four classes according to plant height, it was found that the shorter lines were the latest

to head. The following table shows this comparison:

Average date first head (June)	Number of lines	Average plant height (Inches)
8	21	26-27
8	33	28-29
7	29	30-31
6	17	32-33

Plants of the F_4 lines grown at Akron are all short. It is possible that the adverse weather conditions at Akron had a greater effect on the later heading lines than on the earlier heading lines. The lack of moisture and the high temperatures were undoubtedly more pronounced when the later plants were heading than when the earlier plants were heading. The value of an early maturing variety in sections of limited rainfall is generally recognized.

Lodging

Lodging notes were taken on F_3 and F_4 lines grown in the agronomy nursery and on F_3 and F_4 lines grown in the botany nursery. In all cases where lodging notes taken on the hybrids and aprental varieties are compared, the hybrids show a slightly higher average percentage of lodging than either parent. A summary of the lodging data collected on parental varieties and F_3 and F_4 hybrid lines is given in the following table:

	Number of rows	Lodging, agronomy nursery	Number of rows	Lodging, botany nursery
		Per cent		Per cent
F_3 lines.....	36	7.8	31	3.5
Tenmarq......	2	.0	2	2.5
Minturki.....	2	.0	2	2.5
F_4 lines.....	235	15.6	148	2.3
Tenmarq......	12	14.6	8	.6
Minturki.....	12	15.0	8	1.9

Although plants were selected for stiffness of straw each year it was impossible to overcome this tendency for weak straw in the hybrids. Nearly all of the F_4 segregates had weaker straw than Tenmarq.

Kernel Plumpness and Protein Content

Kernel plumpness notes were taken on bulk samples from several individual plants in each F_3 line and parental check row grown at Manhattan and Colby in 1930, and from parental check rows and a few of the more promising F_4 lines grown at Akron and Manhattan in 1931. Protein determinations were made on bulk samples from several individual plants in each F_3 line grown in the agronomy nursery at Manhattan in 1930.

Kernel plumpness notes taken on the F_3 lines grown in the agronomy nursery at Manhattan in 1930 are distributed as follows:

Per cent plumpness

	83	85	87	Total	Average
Number of F_3 lines...	10	24	2	36	84.6
Tenmarq....	--	1	-	1	85.0
Minturki...	--	1	-	1	85.0

The kernel plumpness of the hybrids varied from 83 to 87 per cent and averaged 84.6 per cent. Tenmarq and Minturki both had an average plumpness of 85 per cent. This is also the modal class of the hybrids.

At Colby under more adverse weather conditions a marked reduction in kernel plumpness was noted in Minturki and many of the hybrid lines. Tenmarq was reduced slightly in kernel plumpness but had much plumper kernels than Minturki and most of the F_3 hybrid lines. The kernel plumpness percentages of the F_3 lines and parental checks grown at Colby in 1930 are shown in the following table:

Per cent plumpness

	65	70	75	78	80	83	85	88	Total	Average
Number of F_3 lines..	1	4	3	3	9	7	2	1	30	78.8
Tenmarq...	-	-	-	-	2	2	1	-	5	82.2
Minturki..	-	1	-	-	-	-	-	-	1	70.0

At Manhattan in 1931 the F_4 lines had an average plumpness note of 78.5 which was only slightly below the average plumpness note of Tenmarq. Minturki had a plumpness note below the average plumpness note of the hybrids. The plump-

ness notes taken on the F_4 lines grown at Manhattan in 1931 are as follows:

	Per cent plumpness					
	70	75	80	85	Total	Average
Number of F_4 lines....	4	26	48	8	86	78.5
Tenmarq.....	-	3	4	1	8	78.8
Minturki....	1	3	4	-	8	76.9

The hybrids varied in plumpness from 70 to 85 per cent.

Kernel plumpness notes taken on 88 F_4 lines grown at Akron, Colo., in 1931 are as follows:

	Per cent plumpness					
	70	75	80	85	Total	Average
Number of F_3 lines.....	6	35	46	1	88	77.4

The hybrids varied in plumpness from 70 to 85 per cent but averaged slightly lower than the F_4 lines grown at Manhattan. The drier weather conditions are no doubt responsible for this reduced plumpness. No plumpness notes were taken on Tenmarq and Minturki grown at Akron.

Tenmarq usually produces a plumper kernel than Minturki. Under favorable conditions Minturki produces kernels as plump as Tenmarq, but under slightly adverse conditions the kernels of Minturki are not so plump as Tenmarq kernels. The hybrids behave very much like Minturki in this respect. In making individual plant selections types resembling Ten-

marq in kernel shape and texture were selected. There were very few F_4 lines resembling Tenmarq in kernel size and shape. Most of the hybrids resembled Minturki in this respect.

The protein determinations made on grain of the F_3 lines grown at Manhattan in 1930 varied from 10.5 to 13.8 per cent. Hybrid lines of lower protein content than Minturki and higher protein content than Tenmarq occurred. The significance of the differences in protein content that were observed are not reliable due to the small number of lines involved. Only 36 hybrid lines and only one parental row of each parent were analyzed. The protein percentages of the F_3 lines and the parental varieties are shown in the following table:

Per cent protein

Number of	10.8	11.3	11.5	11.8	12.0	12.3	12.5	12.8	13.3	13.5	13.8	Average
F_3 lines...	3	2	4	4	6	3	3	6	3	1	1	12.1
Tenmarq....	-	-	-	-	-	-	-	1	-	-	-	12.8
Minturki...	-	-	-	-	1	-	-	-	-	-	-	12.0

The average protein content of the hybrid lines is intermediate between the protein content of Tenmarq and Minturki.

The protein determinations of the F_3 lines are shown graphically in Figure 18.

Fig. 18.-- Protein determinations, F_3 lines of Tenmarq x Minturki, agronomy nursery, 1930.

Wheat-meal-time-fermentation Test of Tenmarq and Minturki

Samples of Tenmarq and Minturki were compared using the wheat-meal-time-fermentation test as described by Saunders (38), Pelshenke (33) and Cutler (14). Determinations of breaking time were made on two samples of each variety grown in the agronomy nursery and three samples of each variety grown in plots at the agronomy farm in 1932. In all cases Tenmarq required a much longer period for the dough ball to break than Minturki. The condition of the dough ball of a Tenmarq sample at the time of breaking of the dough ball in a Minturki sample is shown in Plate V. The time required for the dough balls of Tenmarq and Minturki to break is as follows:

	Minutes to break	Per cent protein	Quality index
Tenmarq (nursery).....	134	-	-
	135	-	-
Average......	134	14.6	9.2
Tenmarq (plots)......	123	-	-
	128	-	-
	121	-	-
Average......	124	12.8	9.7

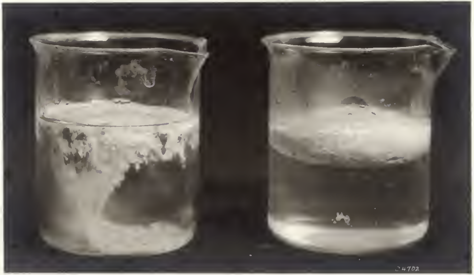


Plate V.-- Dough balls in wheat-meal-time-fermentation test of Minturki (left) and Tenmarq (right). Breaking time for Minturki, 83 minutes, for Tenmarq, 124 minutes.

	Minutes to break	Per cent protein	Quality index
Minturki (nursery)...	80	-	-
	83	-	-
Average.......	81	14.0	5.8
Minturki (plots).....	83	-	-
	86	-	-
	80	-	-
Average.......	83	13.7	6.1

The average time for the dough balls to break was 83 minutes in the five Minturki samples and 124 minutes in the five Tenmarq samples. The quality indices were determined by dividing the average number of minutes required for the dough ball to break by the percentage of protein of the sample.

SUMMARY AND CONCLUSIONS

The purpose of the cross, Tenmarq x Minturki, was to develop an improved variety of wheat for Kansas, and to learn something of the mode of inheritance of resistance to leaf rust and bunt and other characters.

The cross was made in the agronomy greenhouse during the winter of 1926-'27. The F_1 generation was grown in the greenhouse during the winter of 1927-'28. The seed from each F_1 plant was kept separate and space-planted in nursery rows at Manhattan in the fall of 1928 to produce the F_2 population grown in 1929.

F_3 lines selected from individual F_2 plants were grown at Manhattan and Colby, Kan., in 1930. In 1931 F_4 lines selected from individual F_3 plants grown at Manhattan and noted as resistant to leaf rust in the heading stage were grown at Manhattan and Colby, Kan., North Platte, Nebr., and Akron, Colo. F_4 lines selected without reference to leaf rust reaction from F_3 lines grown at Colby in 1930 were also grown at Manhattan in 1931.

F_3 and F_4 lines inoculated with a Kansas composite of physiologic forms of bunt, Tilletia levis, were planted in the botany nursery in the fall of 1930. In the fall of 1931, plants from bunt-free F_4 lines were inoculated with bunt and planted in the botany nursery. Seed of individual plant selections made from bunt-free F_5 lines in 1932 was inoculated with bunt and planted in the botany nursery in the fall of 1932.

F_3 and F_4 seedling plants were inoculated with known physiologic forms of leaf rust, Puccinia triticina, in the two-leaf stage in the botany greenhouse during the winter months of 1930-'31.

Leaf rust studies in the nursery were made on the F_3 and F_4 generations in the heading stage. The F_3 lines grown at Manhattan in 1930 showed either a susceptible, segregating or resistant reaction to leaf rust. The plants in the

segregating rows showed a very close fit to a 3:1 ratio, indicating that resistance to leaf rust in this cross as observed in the nursery is due to a single main genetic factor with susceptibility dominant. The deviation of observed from calculated numbers was 5 ± 5.48. Tenmarq was more than usually resistant to the physiologic forms of leaf rust prevalent in the nursery in 1930, and Minturki was very susceptible.

In 1931, F_4 lines selected from F_3 plants resistant to leaf rust in the heading stage, averaged 24 per cent leaf rust in the heading stage in the nursery. F_4 lines not selected from rust-resistant F_3 plants averaged 43 per cent leaf rust, showing that definite progress was made by selecting rust-resistant plants in F_3. The results obtained in F_4 indicate that multiple factors probably are involved in the inheritance of resistance to leaf rust in this cross. Recombinations occurred which were more resistant than either parent.

In 1931, Tenmarq averaged 35 per cent and Minturki 31 per cent leaf rust in the heading stage in the agronomy nursery. In most seasons Minturki is much more susceptible to leaf rust than Tenmarq. The susceptible reaction of Tenmarq was probably due to the presence of physiologic forms of leaf rust to which Tenmarq shows very little resistance.

F_3 lines from the botany nursery were grown in the greenhouse and inoculated in the two-leaf stage with leaf rust physiologic forms 3 and 9. F_4 lines were inoculated with physiologic forms 9, 15 and 26.

Nearly all of the F_3 seedlings were very susceptible to physiologic forms 3 and 9. Tenmarq was susceptible to physiologic form 9 and showed segregation for resistance to physiologic form 3. Minturki was susceptible to both forms.

F_4 lines selected from F_3 plants resistant to leaf rust in the heading stage were all very susceptible to physiologic form 9 in the seedling stage in the greenhouse. Some of the F_4 lines showed moderate resistance to physiologic form 15, although most of them were susceptible. Two lines exhibited a homozygous resistant reaction. Approximately 50 per cent of the F_4 lines showed some resistance to physiologic form 26, one line being apparently homozygous resistant. This was one of the same lines exhibiting a homozygous resistant reaction in the inoculation studies with physiologic form 15. This line was also very resistant to leaf rust in the heading stage in the nursery. Tenmarq showed segregation for resistance to physiologic forms 15 and 26 in seedling inoculations. This is not surprising since the variety is itself of hybrid origin. Minturki was susceptible to physiologic form 15 and moderately resistant to physiologic form 26.

Plants of the F_3 and F_4 hybrid selections were more resistant to leaf rust in the heading stage than in the seedling stage. This is in agreement with the observations of Johnston and Melchers and Mains and Leighty who observed that varieties of wheat frequently are susceptible to leaf rust in the seedling stage and resistant in the heading stage. There was no close association between the reaction of the hybrids to leaf rust in the heading stage and in the seedling stage. This is probably due primarily to the fact that most of the lines were susceptible in the seedling stage.

The F_3 and F_4 lines inoculated with bunt were grown under identical conditions in the botany nursery in 1931. The percentage of bunted plants in the individual F_3 lines varied from 0 to 23 per cent. The percentage of bunted plants in the F_4 lines varied from 0 to 43 per cent. Parental checks of Tenmarq averaged 24 per cent and of Minturki, 2 per cent bunted plants. Neither the F_2 nor the F_3 generations from which these F_3 and F_4 lines were selected had been inoculated with bunt. In the F_3 generation, 3 per cent of the lines were bunt free, while in the F_4 generation 8 per cent of the lines showed no infection. The relatively large number of bunt-free F_4 lines and the occurrence of types more susceptible than Tenmarq indicate that multiple factors are involved in the inheritance of bunt

resistance in this cross.

F_5 lines representing individual plant selections from bunt-free F_4 lines had an average of 3 per cent bunted heads per row. Under the same conditions, Minturki checks had an average infection of 2 per cent and Tenmarq checks an average of 56 per cent bunted heads. Fourteen per cent of the F_5 lines grown in the botany nursery in 1932 were bunt-free.

No close association between resistance to bunt and leaf rust was observed in the F_3 and F_4 generations.

Very little information on the winter hardiness of the hybrids was obtained. One hundred or more F_4 lines were space-planted in nursery rows at Manhattan and Colby, Kan., North Platte, Nebr., and Akron, Colo., for the purpose of obtaining information on winter hardiness. Practically no winterkilling occurred at any station, though at Akron there was enough killing to give slight indication as to the hardiness of the hybrids as compared to the parents. The F_4 lines grown at Akron had an average winter survival of 91.6 per cent, compared to 91 per cent for Minturki and 87.5 per cent for Tenmarq.

Most of the F_3 and F_4 lines were intermediate in time of heading. Very few types as early as Tenmarq were obtained although the earliest types were selected each year. Since most of the hybrid selections seem to resemble

Minturki, are tall, late and have rather weak straw, it is not likely that a desirable wheat for Kansas will be obtained from this cross. In 1931, the F_4 lines grown at Akron, Colo., appeared to be better adapted than at any of the other stations.

Most of the F_3 and F_4 lines were intermediate with respect to plant height. Most of the hybrid lines apparently carried the genes for leafiness of Minturki. There was no consistent relationship between plant height and date of first heading observed at Manhattan or Colby. At Akron, Colo., the F_4 lines with shorter plants, 26-27 inches, headed about two days later than the taller hybrid types, 32-33 inches. This apparent correlation between shortness and lateness may have been due to unfavorable environmental conditions rather than to any association of genetic factors.

Under the favorable climatic conditions at Manhattan, Tenmarq and Minturki both produced very plump kernels. Under the much more severe climatic conditions at Colby, Minturki did not produce as plump kernels as Tenmarq. Under the adverse conditions at Colby, the hybrids did not produce as plump kernels as Tenmarq. The later maturity of Minturki and the hybrids is probably responsible for the shriveled condition of the grain. The value of early maturity in regions of limited rainfall is generally recognized.

Protein determinations were made on bulk samples from several individual plants in each F_3 line grown at Manhattan in 1930. The percentage of protein in these samples varied from 10.5 to 13.7. The F_3 hybrids averaged 12.1 per cent protein. Tenmarq and Minturki averaged 12.8 and 12 per cent protein, respectively.

Samples of Tenmarq and Minturki were compared using the wheat-meal-time-fermentation test of Saunders, Pelshenke and Cutler. Two samples of each variety grown in the nursery and three samples of each variety grown in plots at the agronomy farm in 1932 were used. The average time for the dough balls to break was 83 minutes for Minturki and 124 minutes for Tenmarq.

LITERATURE CITED

(1) Aamodt, O. S.
Varietal trials, physiologic specialization and breeding spring wheats for resistance to Tilletia levis and Tilletia tritici. Canadian Jour. of Research 5:501-528. 1931.

(2) Ball, Carleton R.
The history of American wheat improvement. Agr. Hist. 4:48-71. 1930.

(3) Biffen, R. H., and Engledow, F. L.
Wheat-breeding investigations at the Plant Breeding Institute, Cambridge. Ministry of Agr. and Fisheries, Research Monograph 4. 1926.

(4) Briggs, F. N.
Factors which modify the resistance of wheat to bunt, *Tilletia tritici*. Hilgardia 4:175-184. 1929.

(5) ----------
Inheritance of the second factor for resistance to bunt, *Tilletia tritici*, in Hussar wheats. Jour. Agr. Research 40:225-232. 1930.

(6) ----------
Inheritance of resistance to bunt, *Tilletia tritici*, in White Odessa wheat. Jour. Agr. Research 40:353-359. 1930.

(7) ----------
Inheritance of resistance to bunt, *Tilletia tritici*, in hybrids of White Federation and Banner Berkeley wheats. Jour. Agr. Research 42:307-313. 1931.

(8) ----------
Inheritance of resistance to bunt, *Tilletia tritici*, in crosses of White Federation with Turkey wheats. Jour. Agr. Research 44:121-126. 1932.

(9) Clark, J. Allen
Segregation and correlated inheritance in crosses between Kota and Hard Federation wheats for rust and drought resistance. Jour. Agr. Research 29:1-47. 1924.

(10) ----------, Florell, Victor H., and Hooker, John R.
Inheritance of awnedness, yield and quality in crosses between Bobs, Hard Federation and Propo wheats at Davis, California. U. S. Dept. Agr. Tech. Bul. 39. 1928.

(11) ----------, Martin, John H., and Ball, C. R.
Classification of American wheat varieties. U. S. Dept. of Agr. Bul. 1074. 1922.

(12) ----------, Martin, John H., and Parker, John H.
Comparative hardiness of winter-wheat varieties. U. S. Dept. Agr. Dept. Circ. 378. 1926.

(13) ----------, Parker, John H. and Waldron, L. R.
Registration of improved wheat varieties. Amer. Soc. Agron., Jour. 21:1173 p. 1929.

(14) Cutler, G. H. and Worzella, W. W.
A modification of the Saunders' test for measuring quality of wheats for different purposes. Amer. Soc. Agron., Jour. 23:1000-1009. 1931.

(15) Dillon-Weston, W. A. R.
The incidence and intensity of <u>Puccinia glumarum</u> Eriks. and Henn., on wheat infected and non-infected with <u>Tilletia tritici</u> Winter, showing an apparent relationship between the susceptibility of wheat plants to yellow rust and to bunt. Annals of Applied Biol. 14:105-112. 1927.

(16) Freeman, Geo. F.
Heredity of quantitative characters in wheat. Genetics 4:1-93. 1919.

(17) Gaines, E. F.
The inheritance of resistance to bunt or stinking smut of wheat. Amer. Soc. Agron., Jour. 12:124-131. 1920.

(18) ----------
Genetics of bunt resistance in wheat. Jour. Agr. Research 23:445-479. 1923.

(19) ----------, and Singleton, H. P.
Genetics of Marquis x Turkey wheat in respect to bunt resistance, winter habit and awnlessness. Jour. Agr. Research 32:165-181. 1926.

(20) Hayes, Herbert K.
Inheritance of kernel and spike characters in crosses between varieties of <u>Triticum vulgare</u>. Studies in the Biol. Sciences (Univ. of Minn.). 4:163-182. 1923.

(21) ----------, and Aamodt, O. S.
Inheritance of winter hardiness and growth habit in crosses of Marquis with Minhardi and Minturki wheats. Jour. Agr. Research 35:223-236. 1927.

(22) ----------, and Garber, R. J.
Breeding small grains in Minnesota. Minn. Agr. Expt. Sta. Bul. 182. 1919.

(23) Hill, Donald D., and Salmon, S. C.
The resistance of certain varieties of winter wheat to artificially produced low temperatures. Jour. Agr. Research 35:933-937. 1927.

(24) Johnston, C. O.
The occurrence of strains resistant to leaf rust in certain varieties of wheat. Amer. Soc. Agron., Jour. 21:568-573. 1929.

(25) ———
Effect of leaf rust infection on yield of certain varieties of wheat. Amer. Soc. Agron., Jour. 23: 1-12. 1931.

(26) ———, and Melchers, L. E.
Greenhouse studies on the relation of age of wheat plants to infection by Puccinia triticina. Jour. Agr. Research 38:147-157. 1929.

(27) Mains, E. B.
Studies in rust resistance. Jour. of Heredity 17: 313-325. 1926.

(28) ———
Effect of leaf rust (Puccinia triticina Eriks.) on yield of wheat. Jour. Agr. Research 40:417-446. 1930.

(29) ———, and Jackson, H. S.
Physiologic specialization in the leaf rust of wheat, Puccinia triticina Eriks. Phytopathology 16:89-120. 1926.

(30) ———, Leighty, C. E., and Johnston, C. O.
Inheritance of resistance to leaf rust in crosses of common wheat, Triticum vulgare Vill. Jour. Agr. Research 32:931-972. 1926.

(31) Martin, John H.
Comparative studies of winter hardiness in wheat. Jour. Agr. Research 35:493-535. 1927.

(32) Newton, R., Cook, W. R., and Malloch, J. G.
The hardiness of the wheat kernel in relation to protein content. Scientific Agr. 8:205-219. 1927.

(33) Polshenke, P.
A short method for the determination of gluten quality of wheat. Cereal Chem. 10:90-96. 1933.

(34) Quisenberry, Karl S.
Inheritance of winter hardiness, growth habit and stem-rust reaction in crosses between Minhardi winter and H-44 spring wheats. U. S. Dept. Agr. Tech. Bul. 218. 1931.

(35) ----------, and Clark, J. Allen
Breeding hard red winter wheats for winter hardiness and high yield. U. S. Dept. Agr. Tech. Bul. 136. 1929.

(36) ----------, and Clark, J. Allen
Hardiness and yield of winter-wheat varieties. U. S. Dept. Agr. Circ. 141. 1930.

(37) Roberts, Herbert F.
The relation of protein content to variety types in American wheat. Jour. Agr. Science 10:121-134. 1920.

(38) Saunders, H. A., and Humphries, S.
The Saunders test. National Inst. of Agr. Bot., Jour. Cambridge, England, 2: 34 p. 1928.

(39) Shollenberger, J. H., and Clark, J. Allen
Milling and baking experiments with American wheat varieties. U. S. Dept. Agr. Dept. Bul. 1183. 1924.

(40) Smith, R. W.
Transferring smut immunity to hard red spring wheat. Amer. Soc. Agron., Jour. 34: 663 p. 1932.

(41) Swanson, C. O., and Kroeker, E. H.
Testing wheat varieties for milling and baking quality. Cereal Chem. 9:10-33. 1932.

(42) Thompson, W. P.
The inheritance of the length of the flowering and ripening periods in wheat. Royal Soc. of Canada, Trans. 12:69-87. 1918.

(43) ----------
The inheritance of earliness and lateness in wheat. Royal Soc. of Canada, Trans. 13:143-162. 1919.

(44) Tisdale, W. H., Martin, J. H., Briggs, F. N., Mackie, W. W., Woolman, H. M., Stephens, D. E., Gaines, E. F., and Stevenson, F. J.
Relative resistance of wheat to bunt in the Pacific Coast States. U. S. Dept. Agr. Bul. 1299. 1925.